THE EFFECTS OF TWO RANGES OF FLUORESCENT LIGHTING SPECTRA ON HUMAN PHYSICAL PERFORMANCE

BY

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by

René E. Chance

Dedicated to Alba C. Chance, my mother,
and the late Fred B. Chance, my father,
parents who raised me with
love and support.

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Abstract of Dissertation Presented to the Graduate Council
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THE EFFECTS OF TWO RANGES OF FLUORESCENT LIGHTING SPECTRA ON HUMAN PHYSICAL PERFORMANCE

By

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The purpose of this study was to examine the effect of fluorescent lighting spectra on 21 variables of human performance both at rest and during exercise. Thirtyfour college-aged women volunteered as subjects for the study. All subjects underwent two treatment sessions--one under warm-white fluorescent light and the other under broad-spectrum fluorescent.

Each session consisted of four and one-half hours. All subjects were exposed to incandescent light for half an hour followed by the four-hour treatment under the pre-determined fluorescent light.

The resting measures taken hourly (four times) included resting heart rate, systolic and diastolic blood pressures, pulse pressure, visual acuity, and reaction time. An exercise test on a bicycle ergometer,PWC (170), was administered at the close of each session with the resulting recovery also being monitored. The fifteen exercise variables included the six-minute measures of heart rate, systolic and diastolic blood pressures, and pulse pressure; final measures of the above; physical work capacity, predicted maximal oxygen uptake;time on bike; half life recovery; and recovery heart rates at one, three, and five minutes.

The significant findings with the resting measures include a lower mean systolic and diastolic blood pressure under broad-spectrum light ($p<.05$). There were no light effects of any significance with any of the other variables.

The exercise test results reveal a significant difference ($p<.05$) for heart rate after six minutes of exercise, favoring broad spectrum. There was also a greater pulse pressure after exercise with broad-spectrum. The predicted maximal oxygen uptake was also significantly higher under the broad-spectrum. The final significant finding was that time on bike was longer under broad-spectrum.

Thus it can be concluded that a four-hour exposure to fluorescent light does affect human performance. From these findings, the writer suggests that broad-spectrum tubes be installed in place of warm-white tubes in an effort to lower environmental stress on humans.

CHAPTER 1
INTRODUCTION

This study has as its focus the effects of classroom lighting on several aspects of human performance and physical fitness. An exploration of the various ramifications of the classroom environment as it contributes to a learning atmosphere requires a close look at the way human physiology reacts to its physical surroundings.

Today there is great interest focused on the study of the interaction between human health and the environment, and justifiably so because human life is, to a large degree, a product of the environment (McVey, 1969). Virtually all human effort these days is leading toward controlled environments (e.g., enclosed cities, undersea and underearth structures, space vehicles) which will take life out of natural surroundings. Thus environment is man's big challenge now and for the future (Biren, 1969, p. 7). While it is obvious that such critical problems as air and water pollution, excessive use of chemical fertilizers and insecticides, and disposal of radioactive wastes must be dealt with, environmentalists must also give attention to one of the most vital cosmic energies of all--light.

Radiation from the sun or from artificial sources is part of the basic environment impinging upon humans. Living organisms contain many compounds capable of absorbing radiation. A living organism is a self-regulating system equipped with many interdependent homeostatic mechanisms. Absorption of radiant energy creates within the system a "disturbance" which leads to activation of these mechanisms (Czerski, 1975).

The tremendous influence of abundant, cheap artificial light on the health of human beings needs to be recognized. There are possible biological consequences to human life when living in artificially lighted environments that differ significantly from the milieu in which life was created (Wurtman, 1975b). Light is potentially too useful an agency of human health not to be more effectively examined and exploited (Wurtman, 1975a).

By design or by accident, the spectra emitted by artificial light sources differ considerably from the spectra under which mammals were created (Wurtman and Weisel, 1969). Fluorescent bulbs have been designed on the premise that the only effect of light is that of enabling people to see. They are efficient and bright because a large fraction of their emitted light is in the green portion of the visible spectrum to which the human eye is most sensitive (Cardinali, et al., 1975). The intensity of radiation emitted at any given wavelength depends on the nature of phosphors, the concentration of mercury vapor in the lamp, and the level of input current (Klein, 1972). The spectra emitted by fluorescent sources can thus be modified at will, limited only by the ability of the chemist to devise novel phosphors (Wurtman, 1975a). It is therefore possible to make fluorescent lamps whose spectral output closely matches that of sunlight (Wurtman, 1975b). In fact, several broad-spectrum bulbs designed to duplicate sun and sky radiation at a temperature of 5000K (the temperature in degrees Kelvin at which a heated black body will radiate noon time sky color) have been developed (Yasunaga et al., 1975; Kleiber et al., 1973).

The responses of life to a particular lighted environment depend on three variables of the illumination: 1) the spectrum of light (e.g., its output at specific wavelengths or colors), 2) its intensity, and 3) the temporal pattern of light exposure (e.g., the number of hours per day that the individual is exposed). All three of these factors have been drastically changed as humanity has moved indoors and taken advantage of artificial light sources (Wurtman, 1975b).

The effects of light on mammalian tissues can be classified as direct or indirect, depending upon the mechanism involved. The direct effects of light are the chemical changes of a tissue that result from the absorption of light energy within the tissue (Wurtman, 1973). The indirect effects of light can be defined as those ultimately mediated by internal chemical signals whose responses depend on the responses of specialized photoreceptor cells to light energy (Wurtman, 1975a).

Problem

Our modern unnatural light environment--with changes being brought about by artificial lighting, glass filters with many uses, air pollution, and electrical devices--is perhaps out of adjustment with many life processes and natural system reactions which have evolved in the human race over hundreds of generations. A mere five generations of humans have been exposed to artificial light, during which time there can hardly be expected any major evolutionary results in human organ systems. According to Ott (1975), we are walling ourselves in behind glass that filters out some of the important rays of the sun and are using artificial light sources that are grossly distorted from the natural balance of all the wavelengths of sunlight energy.

Light energy entering a living system is not destroyed but merely converted into chemical energy which the individual cells use in various ways (Ott, 1974). Therefore, it seems reasonable to assume that if the characteristics of the source of energy (light) responsible for this conversion to chemical energy are altered, the end result will likewise be altered.

Thus, inadequate and harmful fluorescent lighting in school rooms may be a cause of stress that alters physical fitness, work output, and/or performance in students. The correlation between improved fitness and increased physical work output to exposure to sunlight, especially the ultraviolet waves, has been shown through foreign research studies (Ellinger, 1957). Research findings by the present author suggest that exposure to a broad spectrum fluorescent light is an effective means of reducing maximum heart rate immediately after exercise and the related heart rate recovery (Chance, 1978). However, research evidence is not conclusive or extensive in the area of human physiology in response to exercise and the related effect of the lighting environment. The problem researched here concerns possible differences in human performances (performance and physical fitness) when students are exposed to two different spectra of fluorescent lights.

The purpose of the present research was to investigate the effects of warm-white fluorescent light and broad spectrum fluorescent light on several fitness and performance parameters in young adult females--resting heart rate, resting blood pressure, visual acuity, reaction time to sound, exercise blood pressure, heart rate during and recovery heart rate after strenuous exercise, and predicted maximum oxygen uptake.

The specific research tasks inclcuded:

1. Measure blood pressure and pulse pressure, heart rate, reaction time, visual acuity, exercise blood pressure

and pulse pressure, heart rate during and recovery heart rate after strenuous exercise, and predicted maximum oxygen uptake, during exposure to warm-white fluorescent light.

2. Measure blood pressure and pulse pressure, heart rate, reaction time, visual acuity, exercise blood pressure and pulse pressure, heart rate during and recovery heart rate after strenuous exercise, and predicted maximum oxygen uptake, during exposure to a broad spectrum fluorescent light.

3. Compare the results of research tasks (1) and (2).

4. Determine at what point, if any, a threshold of exposure to a light effect is met in one or both of the experimental conditions.

Delimitations

The subjects involved in the present study were female college students (ages 18-25 years).

The study was conducted during the spring of 1982 at Palm Beach Atlantic College. Classrooms were used for the testing.

All testing was conducted during the daylight hours. General Electric fluorescent tubes designated as warmwhite were used as the control. The broad spectrum source was the General Electric "Chroma 50" fluorescent tube.

Further delimitations include the fact that this study did not consider all lighting variables; viz., the threshold of exposure per session was set at four hours, the x-rays emitted by the cathodes in the tubes were ignored, only bulbs of two spectra were used, light intensity was not measured, and critical flicker fusion was not considered. Also, in all cases, the color of the walls was beige.

This study was further delimited because it tested no more than nine performance parameters.

Limitations

The outside pre-experiment activities and light exposure of the subjects were not completely controlled. However, they were asked to avoid strenuous activities on the days of the experiment and to limit light exposure to types other than the experimental and control types during the two-hour period prior to each day's test. Subjects were asked to replicate as closely as possible all pre-experimental activities and situations on each of their testing days.

This study was further limited because the subjects were volunteers. None of the subjects wore any type of corrective lens during the sessions (approximately one-third of the sample did normally wear glasses or contacts, however). Neither the subjects nor the technicians wore digital watches during the testing sessions.

Methods

Experimental Design

The effects of two different types of fluorescent lights on human performance were compared using the variables of resting blood pressure, resting heart rate, visual acuity, reaction time to sound, blood pressure during exercise, heart rate during exercise, postexercise heart rate and recovery, and predicted maximum oxygen uptake. The subjects served as their own controls for the testing.

The order in which the conditions were applied to each subject was pre-arranged to eliminate systematic bias. Each subject was assigned to a treatment order by random drawing.

Subjects

Female college students (ages 18-25 years) at Palm Beach Atlantic College were used as volunteer subjects. Informed consent forms were signed by all subjects (see Appendix A). No subject was allowed to wear eye glasses or contact lenses during the testing sessions.

Forty subjects volunteered for the study. Of these 35 were randomly chosen and 34 completed the testing.

Environmental Conditions

Two windowless classrooms with beige walls were used for the testing. New General Electric warm-white and Chroma

50 (broad-spectrum) tubes were installed in the rooms. All testing was conducted between the hours of 12:00 noon and 6:30 p.m. The thermostats in the classrooms were set at 72F. No digital watches (LED or LCD) were allowed in either of the rooms.

Procedures and Statistical Analysis

Each subject was tested twice during a two-week period in the spring of 1982. All sessions began with the subject spending one-half hour in a room lighted with incandescent light and daylight through windows. The test period followed, consisting of four additional hours of continuous exposure to the pre-determined fluorescent lighting condition.

Hourly measurements (heart rate, blood pressure, visual acuity, and reaction time) were taken following the first quarter hour of each of the four hours of the test session. The exercise test (Astrand Bicycle Test PWC <170>) was administered 15 minutes after the final collection of the resting information. Blood pressure was taken each minute during exercise. Each subject's heart rate was monitored for a five-minute recovery after the stress test.

The results of resting heart rate, resting systolic blood pressure, resting diastolic blood pressure, resting pulse pressure, visual acuity, reaction time, six-minute heart rate, six-minute systolic blood pressure, six-minute diastolic blood pressure, six-minute pulse pressure, PWC (170), final heart rate, final systolic blood pressure, final diastolic blood pressure, final pulse pressure, time on bicycle, recovery heart rates at one, three, and five minutes, and half life recovery were recorded for each treatment of each individual (see Appendices B, C, D).

The data was divided into two sets for analysis--hourly measurements and exercise measurements.

The hourly measurements were analyzed using a repeated measures analysis (ANOVA). This was used to evaluate the difference between the two experimental conditions and the length of exposure.

The exercise test data were analyzed using t-test.

Implications

Light should be recognized as a significant factor influencing biologic function (Logan, 1969). It has perhaps several hundred important effects on bodily functions; but only a few dozen are currently known and an even smaller number are really understood. Modern technology is introducing more and more objects into the daily environment that either block out the spectral energy of natural sunlight or produce abnormal amounts of natural or unnatural energy (Ott, 1977).

Fluorescent lights are the chief means of illumination in public buildings; therefore, the effects of such lights need to be explored. Many activities, whether for physical education or recreation, are performed indoors. Thus, the effect of artificial lights on human performance and fitness is an important aspect to consider.

The student's learning is vitally influenced by the physical surroundings. It has been said that in every classroom there are two teachers, the human teacher who plans and implements the child's educational experience, and that combination of physical forces and forms from which the student derives other kinds of learning (Harmon, 1945). Each of these teachers is of importance to the child's development.

CHAPTER 2
REVIEW OF LITERATURE

Introduction

Every human organism receives a finite number of inputs from the world beyond its integument. These inputs are collectively termed "the environment." They presumably exerted the major influence on human development throughout evolutionary history, and continue to affect life even today. The life of the individual human absolutely requires the presence of some environmental inputs (e.g., dietary protein, atmospheric oxygen, water) and the means of withstanding others (e.g., great extremes in temperature, predators, bacteria in drinking water). Some environmental inputs can be modified by choice; within limits, a person can choose which solid and liquid chemicals will enter the digestive system and whether on any particular day one will be exposed to solar radiation. Other environmental inputs, such as cosmic rays, gravity, the magnetic field of the earth, and certain odors and noises, are, for all practical purposes, inescapable (Wurtman, 1975b).

Human factors research suggests than human life is sensitive to the environment and affected by it. It seems that humans can adapt to their environment, within limits, either to survive or to perform a task. There can be partial acclimatization to certain environments, such as one that is very hot or very cold. Human life can also become sensitized by previous exposure to an environment (Romney, 1975).

Radiation from the sun or from artificial sources is part of the basic environment impinging upon life. Living cells contain many compounds capable of absorbing radiation (Klein, 1972). The earth's mass and gravitational pull hold our atmosphere at a point where an electromagnetic environment which is favorable to life from the lowest to the highest forms is permitted to radiate (Logan, 1969).

The entire sea-level solar radiation spectrum covers from 290 to 2800 nanometers. "Light" is just a small part of it, but all of this radiation is received by the eye, and the eye is affected by it. The "light" part of this spectrum is used by the eye to provide optical images of the outside world. The non-light part of this radiation is used by the eye, synergistically with the "light" part, in cooperation with the skin, to develop homeostasis (Logan, 1969). A living organism is a self-regulating system, equipped with many interdependent homeostatic mechanisms. It appears that a living system does absorb radiant energy which can lead to the activation of these mechanisms. Ott's (1976b) research indicates that many biological responses in both plants and laboratory animals respond to specific narrow bands of wavelengths.

The tremendous influence of abundant, cheap artificial light on the health of human beings needs to be recognized (Logan, 1967). There are possible biological consequences to human life in artificially lighted environments that differ significantly from the milieu in which life was created (Wurtman, 1975b). Research evidence is of interest to architects, lighting manufacturers and engineers, educators, psychologists and others who seek optimum environmental settings (Kleiber et al., 1973). The findings already in hand suggest that light has an important influence on human health, and that our exposure to artificial light may have harmful effects of which we are not aware (Wurtman, 1975a).

The review of the literature that follows is presented in four parts: 1) light--its physical properties and their study, 2) the light environment--natural vs. artificial light, 3) direct effects--the effects of light when directly absorbed by living tissue, and 4) indirect effects--light entering the eyes and the related chemical changes.

Light

Light, refering to that which stimulates the optic nerve, is only one portion of a vast spectrum of the same kind of thing, the various parts of this spectrum being distinguished by different values of a certain quantity (wavelength) which varies (Feynman, 1963, 26-1). Since much of radiation research does not involve the human eye, photometric terminology has little meaning and may provide information that is very misleading. In the study of radiation there are two systems of nomenclature (see Table 1), one dealing with radiation as a physical entity, the other with what is called the photometric or psychophysical system (Klein, 1972).

The three areas of concern in photobiological work, aside from the system under study, are basically physical. These concerns are the generation of radiation, its control, and its measurement (Klein, 1972).

Generation of Radiation

There are many potentially useful sources of radiation, including the sun. The sources that are easiest to control include incandescent and fluorescent lamps.

Incandescent sources

Basically, an incandescent lamp is a hot wire enclosed in a glass envelope. The heated wire emits a continuous spectrum of wavelengths with the bulk (90%) of the radiation energy in the infrared region of the spectrum (Cardinali et al., 1975). Incandescent light sources emit spectra that approximate those of heated black bodies. Their color temperature (the temperature to which a theoretical black body would have to be heated in order to emit such a spectrum) is considerably lower than that of sunlight (Wurtman, 1975b).

Table 1

Comparison of Some Common Photometric and Radiometric Terms and Units

	Photometric		Radiometric	
Defining Term	Term	Unit of Measure	Term	Unit of Measure
Physical Entity	Luminous energy Light	Lumen	Radiant flux Radiant energy	Watt Calorie
Generation	Lumination		Radiation	
Flux Density	Illumination	Ft-candle	Irradiation	mW/cm^2
Intensity		$Lumen/cm^2$		erg/cm^2
Angular Emittance	Brightness	Lux	Radiance	mW/cm^2
Quality	Color	Blue/etc.	wavelength	nanometer (nm)
			Wave number	cm^{-1}
			Frequency	sec^{-1}

Fluorescent sources

The fluorescent light operates by quite a different physical mechanism from that of the incandescent bulb and sunlight (Ott, 1976a, p. 38). Its light output comes not as a consequence of heating but from the activation of chemical phosphors by ultraviolet emissions generated in a low-pressure mercury arc discharge (Wurtman, 1975b).

Basically, a small amount of mercury vapor is excited by the electric current so that electrons in the mercury atoms are moved out of their normal orbital positions and then fall back into orbit, giving up their excitation energy as radiation at specific wavelengths (Klein, 1972). By itself the mercury vapor radiates visible light only in narrow bands of yellow, green, and violet which the fluorescence widens to afford a continuous spectrum, albeit with these peaks of colors (Taylor,1977).

The intensities of these mercury vapor lines in all fluorescent tubes are so great that it is customary in the industry to represent them on wavelength charts as 100 times their actual width and 1/100th of their true height or intensity. This is then represented as the same amount of total relative energy but certainly does not reflect the true situation regarding the actual intensities of the mercury vapor lines (Ott, 1975).

The intensity of radiation emitted at any given wavelength depends on the nature of the phosphors, the concentration of mercury vapor in the lamp, and the level of input current (Klein, 1972). The spectra emitted by fluorescent sources can thus be modified at will, limited only by the ability of the chemist to devise novel phosphors (Wurtman, 1975b). It is therefore possible to make fluorescent lamps whose spectral output closely matches that of sunlight (Wurtman, 1975a). In fact, several broad spectrum bulbs designed to duplicate sun and sky radiation at a temperature of 5500K have been developed (Yasunaga et al., 1975; Kleiber et al., 1973). This is the environmental light composition which has influenced biological action spectra on the earth's surface and is a very definite improvement in fluorescent lighting. Development of a genuine method of eliminating the mercury vapor lines from all fluorescent tubes would be a further major improvement; but until then, it is unfortunately necessary to accept their existence.

Fluorescent bulbs have hitherto been designed on the premise that the only effect of light is enabling people to see. They are efficient and bright because a large fraction of their emitted light is in the green portion of the visible spectrum to which the human eye is most sensitive (Cardinali et al., 1975).

Control of Radiation

At the mundane photobiological level, different responses can be expected when a system is irradiated with different wavelengths. A pigment is definable as a compound that will absorb photons (energy) of a given wavelength. To produce a photoeffect, the system under study must be irradiated with those wavelengths that can be captured by the pigment involved (Klein, 1972).

Photobiological responses to specific colors, or relatively narrow bands of wavelenghts within not only the visible spectrum but also the ultraviolet, give further evidence of the need for scientific control of experimental laboratory light sources (Ott, 1976a, p. 39). Many biological responses are not to the total spectrum of light, but rather to narrow bands of wavelengths. When these bands are missing in an artificial light source, the biological receptor responds as to total darkness (Ott, 1976b).

In placing a filter of any particular color in a white light source, only the wavelengths of light representing that particular color are permitted to pass through. On first thought it might seem that any abnormal growth responses generated when a colored filter is present might be caused by the wavelength of the color involved. However, these wavelengths that do pass through the filter are part of the total spectrum of the original source of white light, and the filter cannot add any additional energy. Therefore, it would appear that any altered growth responses must be due to the absence of the wavelengths blocked by the filter, and that the lack of these wavelengths would cause a biochemical deficiency in cells (Ott, 1974a). Thus, control of radiation exerts much influence over the system under study.

Altering a light source in such a way as to cause a biochemical deficiency might be referred to as causing a condition of malillumination similar to malnutrition which results primarily from what is lacking from a well-balanced diet (Ott, 1974b).

Measurement of Radiation

The duration, the quality, and the quantity of radiation must always be considered in any measurement of radiation. A fourth factor, the polarization, is poorly investigated and is usually ignored except in a few studies on human vision (Klein, 1972).

Duration or temporal pattern is usually expressed as total time of illumination (seconds, minutes, hours, days), if the exposure is constant and uninterrupted. If light periods are interrupted by intervening dark periods, duration is expressed as photoperiod (Klein, 1972; Wurtman, 1975b). The present study incorporated a threshold of exposure effect with the resting measurement at hourly intervals and a four-hour exposure for the exercise test.

Light quality is measured in the photometric system by using color designations (e.g., blue, yellow-orange, and green). The inadequacy of this is obvious since radiation is rarely monochromatic. The radiometric system, however, is very precise. The quality of the radiation is a function of the wavelengths comprising the band (Klein, 1972).

The measurement of light intensity is complicated and expensive. Ideally, the reported measurement should give intensities for each individual wavelength in the radiation band under study. If there is a precise statement of the wavelength band, the intensity value can be viewed as a summation figure. Both the photometric and the radiometric systems have such summation figures, i.e., the lumen or footcandle for the photometric and the watt/cm2 for the radiometric system (Klein, 1972).

Footcandles are defined subjectively in terms of lumens, a unit of brightness per square foot; therefore, the measurement of light from any source in footcandles depends largely upon its output of yellow-green emissions--the larger the proportion of emissions contained within the yellow-green range, the greater the footcandle rating (Wurtman, 1975b). Footcandles and lumens are thus visible units of measurements of light intensity (Yasunaga et al., 1975). Since photoreceptor mechanisms and spectral sensitivities differ among vertebrates, the intensities of light emissions should be measured in absolute irradiance units (Cardinali et al., 1975).

Brightness is a subjective phenomenon and depends upon the extent to which the photoreceptors in the retinas are stimulated. Since, in human beings, these photoreceptors are the most sensitive to visible light in the yellow-green range (555 nm.), most fluorescent light sources have been designed to emit a considerably larger fraction of their total light output in this region of the visible spectrum than the fraction of yellow-green present in sunlight (Wurtman, 1975b).

There is a variety of kinds of measuring instruments differing fundamentally in design and in what they measure. The most familiar instrument is the light or illumination meter. It is also the least expensive and easiest to operate. A light meter consists of a layer of a photo-sensitive chemical that emits electrons when illuminated. The photoreceptive chemical duplicates the same wavelength photosensitivity as the human eye, with the peak in the green at 550 nm. Obviously a cool white fluorescent lamp, emitting strongly at 546 nm, will give a much higher reading than an incandescent lamp with the same total radiation flux. It is just this characteristic of light meters that make them of limited value in photobiological work; it is impossible to compare the radiation emitted by light sources that do not emit identical spectra.

The photometer uses a photocell instead of a photosensitive chemical and with its electronic circuitry is usually more sensitive to lower intensities than are light meters. The galvanometer scale can be calibrated in footcandles or in radiometric units.

For general use, the new radiometers offer the best potential for measuring radiation under clinical and laboratory conditions. Based on photodiodes or thermocouples and compensating electronic circuitry, they can record total irradiation with responses that are equally sensitive to all visible and some nonvisible radiation wavelengths (Klein, 1972).

The Light Environment

The natural electromagnetic environment produced by the solar radiation that penetrates the atmosphere is necessary to life, and for optimal human health (Logan, 1969). Certain variances from optimal health can correspond to variances from natural lighting. Individual differences appear to determine when the effect will occur.

The spectrum of the solar energies reaching the earth is highly restricted. Essentially no wavelengths shorter that 290 nm (i.e., short-ultraviolet and some mid-ultraviolet photons) penetrate the atmospheric shield. Outside the earth's atmosphere, direct exposure to sunlight would be fatal. Life is protected by the filtering action of oxygen

(Willis, 1971). The radiant flux at longer wavelengths increases sharply at the near ultraviolet (320 to 380 nm) and visible (380 to 770nm) portions of the spectrum, reaching a peak in the blue-green range between about 450 and 500 nm; it then decreases gradually into the infrared portion of the spectrum (Wurtman, 1975b). The amount of ultraviolet radiation that penetrates the atmosphere varies markedly with the season (Wurtman, 1975a). The intensity, quality, and quantity of radiation from the visible portion of the solar spectrum do not exhibit remarkable seasonal variation (Cardinali et al., 1975). The actual number of hours of daylight present on any particular day varies with an annual rhythm whose amplitude at any point on earth depends upon the angular distance between that point and the equator (Wurtman, 1975b).

Physically, the visual environment is a three-dimensional pattern of brightness and colors within which the individual grows and functions. Visibility depends on the quality of available light. Thus, the individual's overt and covert responses to that environment merit serious investigation (Kleiber et al., 1973; Baas, 1973).

Creation and Light

Since the beginning of time, life on this earth has evolved under natural sunlight; but today we are suddenly and drastically upsetting this natural light environment

(Ott, 1968a). It seems reasonable to assume that the light sources to which people are presently exposed should not deviate markedly from the lighting environment under which people developed in nature (Wurtman, 1973). An environmental setting developed by natural selection over many thousands of years must be considered to have some merit (VandenHazel, 1970). Since life was created under the influence of sunlight, it is not surprising that many animals, including the human species, have developed a variety of physiological responses to the spectral characteristics of solar radiation and to its daily and seasonal variations (Wurtman, 1975a).

Civilization's migrations from the area of its origin have finally allowed human life to cover the earth; but humankind has been able to do this, not because of any physiological adaptabilities to the immense range of climatic conditions that have been conquered, but by means of human inventions. Human beings are not adapted to the climates of various regions that they occupy. Strip them of the protection of their inventions and they die (Logan, 1947). As a result, people have, so to speak, elected to control their immediate environment instead of submitting to the natural gamble of survival by mutation. In short, people change their impending environment instead of adapting themselves physiologically to fit the environment (Logan, 1967).

The human species has a remarkable ability to develop tolerance to conditions different from those under which it evolved. This has led to the belief that, through technical inventions, people can endlessly modify their ways of life without risk to their mental or physical health. It should not be overlooked, however, that a person can adapt to a synthetic environment only so far as one's genetic code permits (VandenHazel, 1970).

Human beings apparently originated in the semitropics where the average year-round illumination, from 7 a.m. to 6 p.m., is in excess of 3500 footcandles (Logan, 1967). The light intensity provided at eye level in most artificially lighted rooms is on the order of 50-100 Ft-c (160-320 mW/cm2 for cool-white fluorescent light). This level is, in general, less than 10% of that present outdoors in the shade (Wurtman, 1975b). Natural lighting levels as low as present artificial lighting levels are always associated with natural conditions which are hostile to human life (low temperature or storms) (Logan, 1967).

The Artificial Light Environment

By design or by accident, the spectra emitted by most artificial light sources differ considerably from the spectra under which mammals were created (Wurtman and Weisel, 1969). People have produced an electromagnetically polluted environment potentially harmful to life (Baas, 1973).

The daily and seasonal range of intensities and periodicity of different wavelengths of light to which various types of cells are normally exposed is indeed critical. When certain wavelengths of light energy are missing in artificial light sources or blocked from entering the eyes by eyeglasses and especially sunglasses of different colors or tinted contact lenses, then the various pigment granules in the epithelial cells that respond to these particular wavelengths that are missing will not be activated (Ott, 1974a).

Light should be recognized as any other environmental factor (food, chemical) that is known to influence biologic function (Logan, 1969). Light has perhaps several hundred important effects on bodily functions; but only a few dozen are currently known, and an even smaller number are really understood. Since these particular biological effects presumably evolved in relation to a particular lighting environment, architects, lighting designers, and illumination engineers might be well-advised to be conservative about introducing great deviations from "natural" lighting in designing the lighting environments in which people spend their working hours (Wurtman, 1973).

The responses of people to a particular lighted environment thus depend on three variables of the illumination--the spectrum of the light, its intensity, and the temporal pattern of light exposure (e.g., the number of hours per day that the individual is exposed, regardless of day length).

All three of these factors have been changed drastically as the human species has moved indoors and taken advantage of artificial light sources (Wurtman, 1975b).

Light within the range of human vision represents only a very narrow part of the total electromagnetic spectrum, and there are many shorter and longer wavelengths of similar characteristics that are capable of penetrating most types of building materials as readily as the visible spectrum penetrates windows (Ott, 1974c).

Modern technology is introducing more and more objects into the daily environment that either block out the natural sunlight's spectral energy or produce abnormal amounts of natural or unnatural energy. Background radiation of insignificant amounts is generated by an increasing number of devices; and when added together the cumulative effects of the radiation become alarming. Television sets are perhaps most commonly at fault. Other electrical devices which can produce various types of radiation include micro-wave ovens, long distance telephone micro-wave relay towers, police, weather, and airport radar systems, nuclear generating stations, atom bomb tests, medical and dental x-ray machines, fluoroscopes, diathermy machines, radioactive isotopes, electron microscopes, some types of computers and office machines, UHF fields, and AM-FM radio and television broadcasting stations (Brouder, 1977, pp.237-239; Ott, 1974b). Materials that block out natural light energy include spectacle lenses, contact lenses, auto windshields, and window panes.

Fortunately, the trend toward the manufacture of artificial light with an ever greater distortion of the wavelength energy from that of natural sunlight has been reversed. Several companies are now manufacturing a new, improved type of fluorescent light that closely duplicates that of natural outdoor sunlight so that the sun's health-giving benefits may be incorporated into the artificial, interior environment. Other companies are making new types of eye glasses and contact lenses designed so as not to block the normal amounts of near long-wave ultraviolet radiation that do reach the surface of the earth (Ott, 1968a).

Direct Effects

The effects of light on mammalian tissues can be classified as direct or indirect, depending on the mechanism involved. The direct effects of light are the chemical changes in the constituents of a tissue that result from the absorption of light energy within that tissue (Wurtman, 1973; Wurtman and Cardinali, 1976). Sunlight, or its equivalent, initiates photochemical and photosensitization reactions that affect compounds present in the blood, in the fluid space between the cells, or in the cells themselves near the surface of the body (Wurtman, 1975a).

To prove that a particular chemical change in a tissue occurs as a direct response to light, it must first be shown that light energy of the required wavelength does, in fact, penetrate the body to reach that tissue (Wurtman, 1975b). Next, the postulated photochemical or photosensitization reaction must be fully characterized in vivo as well as in vitro (Wurtman and Cardinali, 1976). The identification of an in vivo action spectra is difficult and time-consuming; few, if any, of such spectra have been defined for tissue response occurring beneath the epidermis or outside the eyes (Wurtman, 1975b; Logan, 1969).

Sunlight and Skin

Direct reaction

Natural sunlight acts directly on the cells of the skin, producing both pathologic and protective responses (Wurtman, 1975b). The direct disorders of the skin related to sun exposure may be classified as 1) the immediate types or acute sunburn reactions, and 2) the delayed type that is seen as a result of chronic exposure to sunlight (e.g., premature aging, premalignant and malignant lesions) (Willis, 1971).

Immediate reactions. The immediate reactions result from a single over-exposure to sunburning ultraviolet wavelengths (290-320 nm). When the near and middle ultraviolet regions are combined in the proper proportions, a tanning action occurs which protects from an excessive dosage of middle ultraviolet (Scotto et al., 1976; Willis et al., 1973; Wurtman and Cardinali, 1976). While mild sunburn reactions generally end in an appealingly tanned skin, severe reactions often lead not only to irregular sloughing of the epidermis with a resulting uneven distribution of pigment, but also to systemic signs of toxic reactions (Willis, 1971).

Sunburn can be considered an affliction of civilization. If, weather permitting, people were to expose themselves to sunlight for one or two hours each day throughout the year, their skin reaction to the gradual increase in erythemal solar energies occurring during the winter and spring months would provide them with a protective layer of pigmentation for withstanding summertime intensities of sunlight (Wurtman and Cardinali, 1976).

Delayed reactions. Chronic exposure to the sun for many hours each day over many decades can cause permanent changes in skin structure (Wurtman and Cardinali, 1976). Clinically, there is a change in skin texture manifested by variable degrees of wrinkling, thinning and thickening, scaling, and changes in pigment. These changes are confined to the exposed body surfaces which receive the greatest incidence of sunlight exposure. The total amount of exposure to sunlight required to produce delayed reactions is unknown. However, irreversible damage to the skin occurs with each prolonged exposure to the sun (Willis, 1971).

These aging changes commonly precede, and even seem to create the milieu for, the development of premalignant and malignant lesions (Willis, 1971). The action spectrum for sunburn is believed to be similar to that for skin cancer (Scotto et al., 1976). Today, most investigators believe that the short wave ultraviolet radiation which reaches the earth's surface can produce malignancies in human skin (Herndon and Freeman, 1976; Scotto et al., 1976; Setlow, 1974; Stoein and Wang, 1974).

The association of sunlight and skin cancer has been recognized for nearly a century (Scotto et al., 1976). Genetic factors and the extent of skin pigmentation appear to be of major significance in determining the likelihood that an individual chronically exposed to sunlight will develop a carcinoma. Negro or black-skinned individuals are least susceptible, regardless of skin tone. The incidence of skin cancer is more common among people of Irish descent than would be anticipated if its distribution were random. It is said to be rare among Indians living high in the Andes who are exposed to considerably higher intensities of ultraviolet light (Herndon and Freeman, 1976; Willis, 1971; Wurtman and Cardinali, 1976).

The effects of long ultraviolet rays on human skin are generally believed to be either harmless or protective against sunburn damage. However, DNA metabolism does occur under such wavelengths (Willis et al., 1973). Ultraviolet-induced skin cancer probably arises from photochemical changes in DNA (Setlow, 1974). The observation that a lifetime of exposure to the ultraviolet rays of the sun increases the likelihood of a generally curable skin cancer cannot, of course, be construed as meaning that all exposure to ultraviolet light should be avoided (Wurtman, 1973; Wurtman and Cardinali, 1976).

The total amount of biologically effective ultraviolet radiation varies according to location. However, peak periods of exposure are quite stable, regardless of season or location, with approximately 60% of daily ultraviolet radiation occurring between 10 a.m. and 2 p.m. With present knowledge of ultraviolet exposure patterns one can calculate how to achieve an optimum range of exposure (Setlow, 1974).

Indirect reactions

Ultraviolet radiation exposure in combination with other etiologic factors can cause indirect reactions in skin tissues. Indirect reactions can be classified into two types according to the origin of the basic contributing etiologic factors: 1) photosensitivity of endogenous origin and 2) photosensitivity of exogenous origin. Almost 40 different types of indirect reactions, more commonly called photosensitivity reactions, have been described (Willis, 1971).

Endogenous origin. The most classical reactions of the endogenous type are the porphyryas. In individuals with the congenital disease erythropoietic protoporphyrya, photosensitizing porphyrins are released in the blood stream and absorb long wave ultraviolet light. Intermediates are then generated that are toxic to tissues (Herndon and Freeman, 1976; Ott, 1977; Willis, 1971).

Erythropoietic protoporphyrya constitutes one of the few clinical situations in which the action spectrum for a direct effect of light can be investigated in detail. Symptoms can be induced at will and without major hazard by exposing patients with relatively mild forms of the disease to light (Wurtman, 1975b; Wurtman and Cardinali, 1976).

Exogenous origin. Two types of reactions resulting from exogenous factors may occur when skin is exposed to sunlight--phototoxic and photoallergic. In neither case is sunburn necessary for the reactions to take place. Photoallergy occurs in all races regardless of color. However, phototoxic reactions are rarely seen in Negroes (Willis, 1971).

Photoallergy occurs following topical contact with chemical agents or antigens. When the antigen is avoided, light exposure generally produces no photoallergic result. However, a small minority of individuals experience continued outbreaks whenever just exposed to light. These are referred to as "persistent light reactors." Such individuals become seriously disabled since they cannot tolerate even brief exposures to sun, daylight from the sky, or even some artificial light sources (Herndon and Freeman, 1976; Willis, 1971).

Phototoxic reactions can be induced by either internal administration or by external contact with photosensitizing substances (Willis, 1971). In the past few years, physicians have treated several skin diseases by deliberately inducing photosensitizing reactions on the surface of the body or within particular tissues. The intent is to cause selective damage to the organism or cells causing the disorder. The activated photosensitizers seem to be capable of inactivating the DNA in the virus or unwanted cells (Wurtman, 1973).

Light and Eye Health

Although without light there can be no vision, recent evidence shows that ordinary daylight or light from artificial sources may, in certain instances, cause irreparable damage to the retina. Light from an exceptionally intense source can result in coagulation of protein in the retina. The degree of retinal damage following sudden exposure to light is a function of the light and the duration of exposure (Bellows, 1971; Forrest et al., 1971).

Although the retina is insensitive to pain, exposure to very high levels of illumination normally produces the sensation of pain in the cornea and iris, thereby causing the gaze to be averted or stimulating the blink reflex and protecting the retina from thermal burns (Forrest et al., 1971). Long-ultraviolet rays can produce retinal damage in an individual receiving photosensitizing drugs (Bellows, 1971).

The photoreceptor mechanism that controls the opening and closing of the iris responds to ultraviolet wavelengths as well as to visible light. A subject wearing one ultraviolet transmitting contact lens and one non-ultraviolet transmitting contact lens when under artificial light containing no ultraviolet wavelengths was found to have pupils of the same size. Outdoors, under natural sunlight, the pupil with the ultraviolet transmitting lens was considerably smaller (Ott, 1974a).

Sunlight and Vitamin D

Vitamin D3, or cholecalciferol, is formed in the skin and subcutaneous tissues when mid-ultraviolet light (290-320 nm) is absorbed by its provitamin. It is also derived from eating fish (Baas, 1973; Wilson et al., 1976; Wurtman and Cardinali, 1976). Vitamin D compounds are further transformed by the liver and kidneys to more active metabolites.

A related biologically active compound, vitamin D2, can be obtained by consuming milk and other foods fortified with irradiated ergosterol (Wurtman and Cardinali, 1976). An investigation of human adults found that sunlight is vastly more important than food as a source of vitamin D. Vitamin D3, or its derivatives, was found to be accountable for 70-90% of the vatamin D activity in blood samples. The vitamin D2 present in fortified foods can be toxic causing general weakness, kidney damage, and elevated blood levels of calcium and cholesterol (Wurtman, 1973).

It has been recognized for some years that children chronically under-exposed to sunlight may develop rickets, a deforming disease characterized by a lack of minerals in the bones. This disease can be cured by irradiating the skin with ultraviolet light (Wurtman, 1973).

A study in Boston showed that apparently normal men aged 57-80 deprived of ultraviolet radiation for three months by remaining indoors during the winter in environments illuminated by standard incandescent or cool-white fluorescent sources developed an impairment in the ability of their intestinal mucosa to absorb calcium. Concurrent exposure of similar men for eight hours a day to duro-test fluorescent (full spectrum) light blocked the 40% fall in calcium absorption in the control subjects (Neer et al., 1970).

Phototherapy

Ultraviolet light and its oxidation products are implicated as hazards to the skin and eyes of human beings. However, under appropriate control, they can be used experimentally and clinically to alleviate medical problems perhaps more easily and readily than by some of the more common procedures (Zigman, 1976). It is increasingly apparent that a large number of compounds in the blood and tissues can be chemically altered by solar radiation (Wurtman and Cardinali, 1976).

Phototherapy is used therapeutically in nurseries for neonatal hyperbilirubinemia in place of a complete blood transfer in the jaundiced infants. The condition results from high concentrations of a toxic waste in the blood which the infant is unable to dispose of through the liver and kidneys (Ott, 1977; Yasunaga et al., 1975).

Bilirubin is a yellow conpound produced from the degradation of hemoglobin released when red blood cells die. It is harmful to human tissues (specifically the brain) only during the first few days of life (Wurtman, 1973). All current therapies for neonatal hyperbilirubinemia are based on the premise that if plasma bilirubin can be kept from reaching between 10 and 15 mg/1000ml until the maturing liver becomes able to clear bilirubin from the blood, there will be no brain damage (Wurtman, 1975b).

Some years ago it was discovered that bilirubin in solution could be bleached by light. This observation led to intensive clinical research on the use of phototherapy to lower plasma bilirubin in jaundiced infants (Wurtman, 1975b). When the babies are exposed to the light treatment, their eyes are covered with a blindfold to protect the eyes against possible retinal damage. The skin is exposed to the light for eight hours a day for five or six days (Forrest et al., 1971; Ott, 1977; Yasunaga et al., 1975).

The choice of lamp sources for phototherapy still rests on personal conviction, on advertising claims, and to some degree on trial and error. Blue light is the most effective in decomposing pure solutions of bilirubin. In the intact baby, all full-spectrum light sources tested have lowered plasma bilirubin levels regardless of the fraction of the radiant energy that falls in the blue region of the spectrum (Sisson et al., 1974; Wurtman, 1973; Yasunaga et al., 1975).

Since full-spectrum white light appears to be highly effective in treating jaundiced babies and since exposure to blue light or to other narrow-band lights constitutes a novel and possibly unsafe experience in humanity's evolutionary history, there seems to be little justification at present for explioting this more radical form of phototherapy (Ott, 1977; Wurtman and Cardinali, 1976; Yasunaga et al., 1975). Living systems are composed of many interlocking, closely coordinated and complex parts that include a variety of compounds capable of photoreactions. This fact alone suggests that it is a sound rule to use as narrow a wavelength as possible in all applications of phototherapy. By doing so, one lessens the possibility of damaging or of altering other metabolic systems whose absorption characteristics differ from those of immediate interest (Klein, 1972). It is noteworthy that all the acceptable applications of phototherapy so far use blue or ultraviolet wavelengths that are so grossly missing in our artificial light sources under which modern civilization exists (Ott, 1977).

Photosensitizing Foods and Drugs

A number of widely used drugs and medicines (e.g., tetracyclines, dyes, riboflavin) and certain constituents of foods are potential photosensitizers. Within the body they can be activated by light, thus producing substances that can cause tissue damage in sensitive persons (Saltarelli, 1977; Wurtman and Cardinali, 1976).

The normal dose rate of almost every drug has been established for people living mostly under artificial light. When patients take a photosensitizing drug and go into sunlight the ultraviolet wavelengths are blamed for causing any abnormal side effects (Ott, 1977).

Light can influence the effectiveness of nutritional elements. If the specific wavelengths to which certain vitamins react are of very low energy or totally lacking in an artificial light source, a megadose would be required to bring about normal reaction. If the wavelength absorption characteristics of a food or a drug happen to coincide with a peak of energy in an artificial light source, the result could be an allergic type of response or an overreaction (Ott, 1977). With increasing knowledge of the relationship of nutrition to human health and behavior, it becomes apparent that the interaction of nutrition and light must also be considered.

Indirect Effects

Radiation emitted from artificial or natural light sources produces photochemical, thermal, and psychological effects and also introduces thermal and chemical energies into people. Chemical energies give rise directly to neuroendocrine signals which monitor metabolism and affect the body's total equilibrium with the environment (Logan, 1967). It has long been recognized that various colors may have differing psychological effects on humans, but it is now evident that colors are only a very vague way to identify light energy. Some psychological responses may be related to actual physiological reactions to specific wavelengths of radiation and its direct effect on the endocrine system

(Ott, 1968; Saltarelli, 1977). To better understand psychological reactions to light energy, research must move beyond the physical factors of eye mechanics and the visual tasks into the area of perceptual/psychological prosesses which affect behavior (Bartholomew, 1972).

The indirect effects of light can be defined as those ultimately mediated by endogenous chemical signals whose amplitudes depend on the responses of specialized photoreceptor cells to light. Light activates a photoreceptor cell; this in turn activates a train of cells specialized for communications, causing a release of neurotransmitter or the secretion of a hormone. The neural or hormonal signal actually produces the light effect (Wurtman, 1975a; Wurtman and Cardinali, 1976).

Three criteria must be met before a particular mammalian cell can be classified as a photoreceptor. These are: 1) anatomic--the cell must have organelles thought to be the loci of the photochemical transduction process, 2) chemical--a vitamin A photopigment must be found in the cell, and 3) physiologic--the cell must be shown to be essential for the occurrence of the physiologic response to light and its destruction must block the response. With these criteria applied, only the retina has been clearly shown to contain photoreceptor cells in the adult mammal (Wurtman, 1975b; Wurtman and Cardinali, 1976).

Light acts through the retina to control several glands and many metabolic prosesses. Light, or its absence, induces biologic function. Alterations in environmental lighting can produce marked, and sometimes pathological changes in the body's metabolism (Baas, 1973; Cardinali et al., 1975; Ott, 1976b).

The Eyes' Dual Function

Relatively recent studies suggest that the functions of the eye go further than strictly vision. Indirect effects of light, like vision, result from nervous impulses generated by light impinging on retinal photoreceptors (Ott, 1974a; VandenHazel, 1970; Wurtman, 1973).

Tests have shown that exposure to conventional fluorescent lights may adversely affect visual acuity and increase fatigue. Kleiber and colleagues (1973) investigated whether a full-spectrum fluorescent light would have effects on the ability to study different from those of a cool-white fluorescent light source. In college students visual acuity generally improved after four hours of study under full-spectrum lighting. A decrease in critical flicker fusion (the point at which the eye perceives "flickering" light from a fluorescent source as continuous) was significantly less under full-spectrum than under cool-white. From these results it may be concluded that studying under full-spectrum light is less visually fatiguing than studying under cool-white sources.

The nonvisual responses of the eye to wavelengths of light raises the question as to the effect of tinted lenses, sunglasses, and artificial light sources that produce a distorted spectrum of light entering the eye. Since most of the neuroendocrine effects of radiation in mammals seem to result from stimulation of the retina, it appears likely that the proportion of wavelengths emitted by a light source or blocked by a filter (e.g., contact lenses, window glass, eye glasses, or sunglasses) might similarly influence the eye's capacity to cause neuroendocrine responses (Ott, 1976b; Wurtman and Weisel, 1969).

Extraretinal photoreception has been convincingly demonstrated in some members of all classes of vertebrates in situations where the perception of environmental light cycles is important. The evidence for the existence of extraretinal light reception is least convincing in mammals (Menaker, 1971). Time-lapse cinemicrographic studies, utilizing the tissue culture method of growing pigment epithelial cells of the retina of a rabbit's eye, revealed variations in the responses of the pigment granules with alterations in the intensity, periodicity, and wavelength of light. These cells are located at the point where the rods and cones terminate and are thought to have no function related to vision (Ott, 1974a).

Biologic Rhythms

The periodicity of many internal functions is controlled via the retinal photoreceptors. It appears that changes in light intensity and periodicity as experienced in nature may be needed to synchronize internal rhythms (VandenHazel, 1970; Wurtman, 1975a).

The amount of time that all living things are exposed to light varies within two cycles--a 24-hour light-dark cycle of day and night, and an annual cycle of changing day length, absent only at the equator. Annual rhythms in sexual activity, hibernation, and migratory behavior are widespread among animal species. The physiological significance of these rhythms probably derives from their ability to synchronize the activities of individuals within a species with regard to one another and with regard to their changing environmental conditions. For human beings the pressure of the environment to adapt is of less significance. Psychosocial factors quite possibly are of greater importance than light cycles in generating or synchronizing biologic rhythms (Wurtman and Cardinali, 1976; Zuker, 1976).

Cycles in environmental lighting may interact with biologic rhythms in several ways. The light cycle may induce the rhythm. In this event, placing a mammal in an environment of continuous light or darkness should rapidly abolish the rhythm. Rather than inducing the rhythm, the light cycle might simply entrain it, causing all animals in the same species to exhibit maxima and minima at the same time of the day or night (Wurtman, 1975a).

Relatively little information is available concerning the action spectra or intensities required for light to generate or entrain daily rhythms in mammals. It is known that light is the dominant environmental input affecting rhythms and that light exerts its effects indirectly via retinal photoreceptors (Wurtman and Cardinali, 1976).

There is little doubt that someone who always works under artificial light--especially children--will experience physiological difficulties, although these may not be immediately noticed. There is the possibility of an actual breakdown of a child's health as a result of continued interference with the biologic rhythm (VandenHazel, 1970; Romney, 1975).

Gonadal Function

Environmental lighting has been shown to influence the maturation and subsequent cyclic activity of the gonads in all mammalian and avian species thus far examined. The particular responses of each species to light seem to depend on whether the species is monoestrous or polyestrous. The gonadal responses of each species to light also seem to depend on whether its members are physically active during the daylight or during the night (Wurtman, 1975a).

In mammals and birds, as in vertebrates in general, reproduction is synchornized to culminate when conditions of the environment favor survival of the offspring (Cardinali et al., 1975). In adult mammals only the retina appears to contain the photoreceptor cells necessary for stimulating gonadal responses. The action spectra for the effects of light on mammalian gonads have not yet been identified (Wurtman and Cardinali, 1976).

Studies have shown that the gonads of rats maintained under cool-white fluorescent lighting grow more slowly than those of animals exposed to a full-spectrum fluorescent source. Female rats kept under full-spectrum tended to become pregnant at a younger age than animals kept under the cool-white source (Wurtman and Weisel, 1969). Thus the effects of a particular light source on gonadal growth depend upon the spectral characteristics.

Piacsek and Hautzinger (1974) examined the effects of daily duration, intensity, and spectral composition of light exposure on the sexual maturation of female rats. Exposure to either 22 or 24 hours of light/day significantly advanced vaginal opening when compared to 14 hours/day exposure. This suggests that duration of light exposure becomes important only when a certain threshold is exceeded. It seems that environmental photoperiod affects the synthesis as well as the release of gonadotropins (Cheng, 1976).

Male hamsters raised for 15 weeks under conventional cool-white fluorescent lighting demonstrated retarded testicular development, resulting in immature seminiferous tubules and no spermatogenesis when compared to hamsters raised under sunlight-duplicating indoor lighting (Sharon et al., 1971).

Capacity to perceive light influences sexual maturation in human beings. Blindness in humans is associated with early gonadal maturation (Wurtman, 1973). Girls blind from birth have a significant acceleration of sexual maturation, having their first menstrual period about a year earlier than non-blind girls (Wurtman and Zacharias, 1964).

Photoperiod appears to have an effect on human gonadal function. When the solar electromagnetic field is practically absent for long periods such as in polar regions inhabited by Eskimos, the women neither menstruate nor conceive during the long polar night (Logan, 1969).

Endocrine Function

There is abundant evidence that light influences growth and secretory activity of several endocrine organs (VandenHazel, 1970; Wurtman and Axelrod, 1964; Wurtman and Weisel, 1969). Light entering the eyes is known to stimulate activity in both the pituitary and pineal glands and possibly other areas of the mid-brain region that control the endocrine system and the production of hormones (Moore et al., 1967; Ott, 1975).

The pineal of the mammal is a neuroendocrine transducer. It responds to nervous signals by releasing more or less of its hormone, melatonin, into the blood stream (Wurtman, 1973).

The best-characterized indirect effect of light on any process other than vision is probably the inhibition of melatonin synthesis by the pineal organ of mammals (Karasek, 1971; Wurtman, 1975a). Synthesis of melatonin is depressed in animals maintained in darkness (Moore et al., 1967). Through the secretion of melatonin and of some as yet undefined low molecular weight peptides, the pineal participates in the control of neuroendocrine rhythms such as seasonal cycles in gonadal function (Wurtman et al., 1968).

The normal cycle of environmental lighting, to which most animals and human beings are exposed, generates a parallel rhythm in pineal metabolic functions. Thus a major function of the pineal seems to be the production of a signal whose amplitude depends upon time of day and environmental lighting (Cardinali et al., 1975).

Caries Development

Sharon and associates (1971) have shown that immature golden hamsters that were fed a diet intended to produce cavities developed a significantly greater incidence (five fold increase) of dental caries when raised for a period of 15 weeks under standard cool-white fluorescent lighting than hamsters raised for the same period under full-spectrum fluorescent lighting.

A follow-up study by Feller and colleagues (1974) showed that the caries reduction by full-spectrum light as compared to cool-white light was equaled by low illumination from incandescent light. These results do not indicate that ultraviolet deprivation will necessarily increase caries incidence. However, they do validate the concept that environmental lighting, probably in the visible spectrum, affects the incidence of cavities.

Inasmuch as both groups of animals were fed a cariogenic diet and the housing conditions were the same except for the lights, it would appear that there is a humoral mechanism involved in the protection afforded the animal under full-spectrum or incandescent light, initiated by the effects of light on the skin or the eyes (Mayron et al., 1975).

It has been shown that first- and second-grade children who had been in classrooms under cool-white fluorescent lighting developed a significantly greater incidence of dental caries as compared to children in classrooms with full-spectrum lighting with radiation shielding (Mayron et al., 1974).

Salivary Flow

The nerves that carry light-dependent instructions from the brain to the pineal also run to the parotid gland, a salivary gland. The rate of saliva formation in humans also depends upon the available light. Salivary flow is minimal during light deprivation, either by blindfolding or by room darkening, but it attains near maximal flow rates when people are exposed to as little as 0.1 Ft-c of light. Therefore, not the entire spectrum of light is required; and only a slight intensity of light is necessary to elicit salivary flow (Shannon et al., 1975; Wurtman, 1973).

Mandel (1974) has reviewed the relationship of saliva to caries and, in terms of salivary flow rate, has indicated that no consistent correlation could be found with incidence of cavities.

Alcohol Consumption

The possible relationship of alcoholism and the pineal gland is under study. The evidence that darkness increases alcohol consumption under certain circumstances is very strong (Ott, 1976; Sinclair, 1972).

Animals exposed to ultraviolet light show a marked preference for alcohol solution, while those exposed to cool-white fluorescent light show a marked preference for water. Control experiments with light sources varying from 200-2200 lm, however, failed to show that light intensity has any effect on alchhol consumption (Wilson et al., 1976). There are no studies which deal specifically with humans.

Cancer

Some doctors have said that cancer is caused by a virus. Viruses are sometimes described as abnormal chemicals within the cell. It is suggested that there may be a relationship between the abnormal cell chemistry associated with viruses responding through the process of light sensitivity to an incomplete or unbalanced light spectrum (Ott, 1974a).

If light energy is associated with cancer, then the question might be raised as to the comparative cancer rate of people still living under primitive conditions with those in "Third Wave" nations. As America has become a "glassed-in people" over the last half century there has also been an acceleration in the incidence of cancer (Dunlop, 1963; Logan, 1967; Ott, 1977).

Hyperactivity

There are several known environmental causes of hyperactive behavior, among them chronic arousal or stress, allergy, malnutrition, toxicity, and television radiation. It would appear that improportioned lighting and/or radiation can have similar effects. It may be that these factors are simply stress-inducing in particular children and may have nothing to do with the particular susceptibility of these children to stress (Mayron et al., 1974).

A study of the effects of two types of fluorescent lighting, cool-white and full-spectrum with radiation shielding, was performed on first-grade children in four windowless classrooms in a Florida school. The results of this five-month study indicated that hyperactivity was decreased in the two rooms with full-spectrum lighting with radiation shielding and increased in the two rooms with conventional cool-white lights (Mayron et al., 1975).

This may indicate that hyperactivity is a radiation stress condition. Improvement in the Florida first graders occurred when that part of the visible spectrum, which is lacking in standard artificial light sources, was supplied and excessive radiation was eliminated (Ott, 1974c).

Autism

One of the most puzzling characteristics of the syndrome of autism is the disturbance of motility. Some behaviors classed under this rubric are repetitive and stereotyped. This behavior has stimulated much research and interest, probably because its occurrence is associated with a diminished responsiveness to environmental stimuli (Colman et al., 1976).

The clinical observations of an autistic boy in a classroom situation revealed that he showed less repetitive behavior and seemed to learn faster when the fluorescent illumination in the room was turned off and the classroom was illuminated only by sunlight. A controlled experiment concerning the repetitive behaviors in six autistic children demonstrated that fluorescent background lighting increased the amount of repetitive behaviors when compared to incandescent light (Colman et al., 1976).

Cognitive and Affective Studies

Economic reasoning considers the short-term economies rather than the long-term effects of windowless work areas on the health of people. The synthetic urban environment of non-fenestrated schools, offices, and factories could possibly contribute to the chronic conditions of neurosis and physiological disturbances which show up as degenerative diseases beginning in early adulthood (VandenHazel, 1970). Windowless environments appear to induce greater absenteeism as well as other "escape" behaviors (Romney, 1975).

Karmel (1965) studied the psychological effect of windowless classrooms through the drawings of high school students. The findings that students in the windowless school drew windows significantly more often than their peers in the fenestrated school was interpreted as a lack of identification or fewer positive feelings about their school. Karmel suggested that there were more unhappy or maladjusted children attending the windowless school.

Romney (1975) studied the effect of a windowless environment on the cognitive and affective behaviors of elementary students. No significant differences were noted in performance on a perceptual task under either environmental condition. Rote learning tasks also showed no difference in performance as related to the window situation. Aggression increased in all windowless situations. Romney suggested that the environment plays a more important role in emotional and social well-being than in the learning process.

An empirical study of the effects of a windowless learning environment and pupil achievement showed no measurable effects on student learning. This research did not consider the physiological or psychological effects of light itself (Baas, 1973).

Two experiments tested whether full-spectrum fluorescent lights would have effects on classroom behavior and the ability to study different from those of cool-white fluorescent lights (Kleiber et al., 1973). Videotapes of classroom behavior and post-seminar questionnaires indicated no significant differences in variables dealing with classroom interaction, seminar effectiveness and mood. In the second experiment only one subjective variable (lively-lethargic) out of 23 showed a statistically significant difference between lighting conditions. This difference demonstrated a tendency for subjects to become less lively or more lethargic after four hours under the cool-white light, while there appeared to be no change under the full-spectrum.

Logan (1967) suggests that light (intensity, duration, and spectrum) affects the efficiency of mental processes. He terms this a "photo-cognitive" factor. The lighting of a school building should be considered an active element of the total educational environment.

People tend to be unaware of their luminous environments. Early training in schools could help children to recognize the value of proper lighting (Baas, 1973).

Painter (1975) reports that teachers dislike cool-white fluorescent lighting in their own classrooms. Teachers noticed that there were fewer cases of headaches, nausea, and irritability in rooms with incandescent lights.

Soviet Studies

Soviet scientists have been the first to make practical, large-scale applications of what Logan (1969) calls "bio-lighting." They are developing a literature of the pathology of light illumination.

The Soviet government has established mandatory irradiation standards for ultraviolet exposure for people working in certain industries (Wurtman, 1973). Coal miners are given suberythemal doses of ultraviolet light daily on the theory that the radiation provides protection against the development of black-lung disease. The mechanism of the supposed protective effect is not known (Wurtman, 1975a).

Romney (1975) reported that research in the Soviet Union has shown negative consequences in factory production as a result of continuous usage of artificial lighting. The Soviet government seems to be concerned with the well-being of their students as effected by the light environment in school (VandenHazel, 1970).

One Soviet experiment showed that school children had 30% fewer colds when small amounts of ultraviolet light was added to conventional lighting (Peterson, 1976).

Fluorescent sunlight lamps were compared to standard fluorescent lamps in a study of the long-term effects upon students in the U.S.S.R. There were more favorable effects upon the health and physical development of the children under the full-spectrum sources. The pupils exposed to the sunlight lamps had a shorter reaction time to light and sound, were less easily fatigued, and showed an improved working capacity (Kleiber et al., 1973).

Electromagnetic energy in the microwave range has been put to use as military offensive and defensive operations, weather forecasting, tracking and communications in exploration of outer space, medical industrial, and consumer use. A review article by Michaelson and Dodge (1971) presents Soviet views on microwave exposure and possible damage to human beings.

Some Soviet investigators describe the thermal nature of microwaves; the majority, however, stress non-thermal or specific effects at the molecular and cellular level from low-level microwave exposure. While non-thermal effects of microwaves are entirely possible they have not as yet been as well substantiated physiologically as have thermal effects. The importance of the difference between the Soviet and Western views is readily apparent when it is realized that practical consideration of Maximum Permissible Exposure is based on the acceptance or rejection of non-thermal effects of microwaves as biologically significant (Broudeur, 1977, p. 43).

Soviet investigators suggest that chronic irradiation of animals with low intensity microwaves may induce functional changes in the nervous and cardiovascular systems without a rise in tissue temperature. Higher field intensities produce a thermal effect that can damage brain and testes, cause internal hemorrhage, burns, neurosis of tissues,and produce lenticular opacities. Soviet studies are generally subject to criticism because of limited statistical analysis, inadequate controls, and the intrinsic difficulty of objective interpretation of the findings.

Conclusion

Any one of the observations that has been presented here probably would not appear too striking in itself.

However, taken as a whole, they point to the theory that human beings are indeed adapted specifically for their natural environment. Any substantial alterations of the light environment--through the use of artificial light sources or other radiation-emiting objects, or through the change of the normal spectrum of light which enters the eyes--must be examined from a standpoint of potential hazards.

Solar radiation constitutes an essential and ubiquitous component of the human environment. Besides serving as the ultimate source of food and energy, it has also acted directly upon human physiology to alter chemical composition, control the rate of maturation, and drive or entrain biological rhythms (Wurtman, 1975b). The biologic effects resulting from exposure of a living system to radiant energy may be classified as: 1) early (immediate) direct effects, 2) early (immediate) indirect (secondary) effects, or 3) late (delayed) effects (Czerski, 1973).

The problems of the synthetic environment are intensified by the fact that non-personal, usually economic, interests are given priority over basic human needs (VandenHazel, 1970). Packaging people so that their indoor artificial environment is compatible with them is the architect's responsibility, but guidelines need to be provided (Logan, 1969). It is hoped that biological and medical scientists will pursue studies so that they can dictate the requirements for the proper radiation of life (Ott, 1965).

CHAPTER 3
METHODS

Sample

Female college aged (18-25) volunteers were used as subjects. All were students at Palm Beach Atlantic College. Informed consent forms (Appendix A) were signed by 40 volunteers. From this sample, 35 were randomly chosen to participate in the study. Of these 35, 34 who completed the testing.

Fourteen of the subjects were varsity athletes at the college. The remaining 20 subjects were relatively untrained individuals.

None of the subjects were allowed to wear eyeglasses or contact lenses during any of the testing sessions. There were, however, 12 subjects who normally wore corrective lenses. None of these subjects suffered any observable side effects, other than less than perfect vision, while not wearing their glasses.

All subjects were aware that light was an experimental variable. However, none of the subjects had any knowledge as to which condition was warm-white and which was broad-spectrum.

Technicians

Three technicians assisted the author with the administration of the performance tests. The head technician was a physical educator. Two registered nurses also served as technicians. The author monitored all testing and data collection. Subjects assisted the technicians in the recording of the data.

All of the technicians were familiar with the battery of tests being given. None had any knowledge as to the type of lights in either of the classrooms. The technicians were aware that light was the major variable under investigation.

Environmental Conditions

The lighting environment was arranged with the aid of the electricians, Physical Plant Department, Palm Beach Atlantic College. New General Electric warm-white tubes were installed for the control environment. New General Electric Chroma 50 (broad-spectrum) tubes, for experimental treatment, were installed by the electricians. The light level (intensity) was duplicated by using rooms of the same size (40'X15') and with identical light fixtures (each room with three fixtures, each having three four-foot tubes). The light fixtures were covered with a metal grid, rather than a plastic cover.

Windowless rooms were used for the testing. Both of the classrooms had beige colored walls. All testing was conducted during the afternoon hours and prior to sundown so as to partially control for the background radiation.

Temperatures in the rooms were maintained at 72F. Each room was controlled by an individual thermostat.

Equipment and Supplies

The monark friction-type bicycle ergometer was used to provide a controlled workload. A bowles-type stethoscope and an aneorid spygmomanometer were used for monitoring blood pressure. A Snellen eye chart was employed to measure visual acuity. Reaction time was determined by a Dekan timer. A Timex wall clock was used to monitor times for exercise and recovery during the stress test.

Procedures

Each subject was tested twice during a two-week period in the spring of 1982. All sessions were held on Mondays, Wednesdays, Fridays, and Saturdays of the two weeks. Each of the conditions was administered for four and one-half continuous hours on a separate day between 12:00 noon and 6:30 p.m. The order (two possible treatment orders) in which the conditions were applied to individuals was prearranged by a random drawing to eliminate systematic bias.

The subjects were allowed to choose the two days they came in for testing.

All sessions began with the subject spending one-half hour in a room lighted with incandescent light and daylight through windows. The test period followed and consisted of four additional hours of continuous exposure to the pre-determined fluorescent lighting condition. During any given session there were from one to seven subjects per room.

Hourly measurements (heart rate, blood pressure, visual acuity, and reaction time) were taken following the first quarter hour of each of the four hours of the test session. The exercise test was administered 15 minutes after the final collection of the resting data.

Throughout the testing session subjects were permitted quiet activities such as study or talk. No eating was allowed. Subjects were allowed to drink water.

Testing and collection of data were monitored by the author. Three technicians (including two registered nurses and one physical educator) administered the tests. Subjects served as recorders for the performance tests.

The data collected included resting performance tests measured hourly and one final exercise test on a bicycle ergometer which included a five-minute monitored recovery.

Hourly Performance Tests

During each hour of the session four resting measurements were taken. The order of the hourly test administration was 1) heart rate, 2) blood pressure, 3) visual acuity, and 4) reaction time.

Resting heart rate was taken by palpation of the carotid artery with gentle pressure for one minute. All subjects were measured while seated.

The resting arterial systolic and diastolic blood pressures were measured using a Bowles stethoscope and an aneroid spygmomanometer. Both the systolic blood pressure, identified by the first pulsating sound, and the diastolic blood pressure, identified by the ending of a muffled sound, were recorded in a ratio. All readings were taken on the right arm. One reading was taken per hour.

Visual acuity was measured using a Snellen chart. The subjects were standing at a distance of 20 feet from the chart. Measurements were taken with the right eye first, followed by the left eye and, finally, with both eyes.

The reaction time test was a test of hand movement. While seated the subject placed the right hand, palm down, on a marker. At the sound of the buzzer the object was to move the hand to the left and hit the force plate (12 inches away) with the right hand. Each subject was given three trials.

Exercise Test

The exercise test was the Astrand Bicycle Test PWC(170) as described by Astrand and Rodahl (1977,291-237). It was administered as follows: Each subject began with the ergometer workload set at 600 kgm/minute. This workload was maintained for the first six minutes of exercise. Heart rate was taken the last ten seconds of each minute. The workload was increased 150 kgm every six minutes of exercise. The work was terminated when a heart rate of 170 was reached or upon subject proclaimed fatigue.

Arterial systolic and diastolic blood pressures were taken each minute during exercise. Each subject's heart rate was monitored continuously by palpation at the carotid artery for a five-minute recovery. The subject remained seated on the bicycle during this recovery.

Experimental Design and Statistical Analysis

The effects of two different types of fluorescent lights on human performance were compared using the variables of resting arterial systolic and diastolic blood pressure,pulse pressure, resting heart rate, visual acuity, reaction time to sound,systolic and diastolic blood pressures and pulse pressure during exercise, heart rate during exercise, post-exercise heart rate and recovery at one, three, and five minutes, half life recovery, PWC(170), and predicted maixmum oxygen uptake. The subjects served as their own controls for the testing.

The order in which the conditions were applied to each subject was pre-arranged to eliminate systematic bias. Each subject was assigned to one of the two treatment orders by random drawing.

Neither the subjects nor the technicians were aware of the exact lighting conditions. All of the participants did know that the light was a variable under consideration.

The resting measures taken hourly for four hours were analyzed using a repeated measures ANOVA. The exercise and recovery measures were analyzed for statistical significance using nonindependent t-tests.

CHAPTER 4
RESULTS AND DISCUSSION

Introduction

A one-group, two treatments design taking measurements of six resting variables and 15 exercise and recovery variables was administered to 34 female subjects. These tests measured resting performance parameters and the subjects' levels of fitness. A repeated measures analysis of variance (ANOVA) was used to determine statistical significance between the means of the two treatments over time in each of the six resting variables. A t-test for nonindependent samples was used to determine statistical significance between the means of the two treatments in each of the 15 exercise and recovery variables. The .05 level of significance was needed for statistical significance.

Presentation of Results

The discussion of the findings which follows is divided into two major sections. Part one analyzes the six variables which were measured hourly during rest. The second section includes the results of the exercise test and the related recovery.

Results of Hourly Tests

Resting heart rate

Table 2 summarizes the ANOVA for the resting heart rate measurements. Two sources of significant difference include the time (T) effect and the light-time (LT) interaction.

The LT interaction is analyzed in Table 4 and Figure 1. A steady drop in resting heart rate is shown for the broad-spectrum condition, whereas under warm-white the resting heart rate dropped slightly for the first three measures then rose a slight amount for the final measurement.

Systolic blood pressure

Table 5 summarizes the ANOVA for the systolic blood pressure measurements. Three sources of significant difference include the L effect, the LT interaction, and the light-time-order (LTO) interaction.

The LT interaction is analyzed in Table 7 and Figure 2. Under the warm-white condition the systolic blood pressure showed a general rise from hour one to hour four. The broad-spectrum effect on systolic blood pressure was a general fall from hour one to hour four.

The LTO interaction for systolic blood pressure is analyzed on Table 8 and Figure 3. The second treatment for each group was ignored to disregard the order effect. The

Table 2

Summary ANOVA Table for Resting Heart Rate

SV	SS	DF	MS	F	P
Order (O)	63.09	1	63.09	0.16	0.6920
Error	12634.95	32	394.84		
Light (L)	1.94	1	1.94	0.03	0.8706
OL	86.06	1	86.06	1.19	0.2827
Error	2306.36	32	72.07		
Time (T)	1372.54	3	457.51	31.24	0.0000
TO	94.77	3	31.59	2.16	0.0981
Error	1405.80	96	14.64		
LT	164.86	3	54.94	3.26	0.0250
LTO	2.09	3	0.69	0.04	0.9887
Error	1620.16	96	16.87		

Table 3

Mean Scores and Standard Deviations for Resting Heart Rate

		Treatment Order AB				Treatment Order BA			
		Hour				Hour			
		1	2	3	4	1	2	3	4
A	X	73.23	70.11	69.76	68.64	74.82	72.41	70.52	72.35
	S	9.37	8.55	8.54	7.88	9.27	7.37	9.31	6.86
B	X	77.05	71.52	70.52	67.82	75.88	72.00	68.94	69.47
	S	8.89	8.91	7.55	7.45	9.68	7.87	7.84	7.50

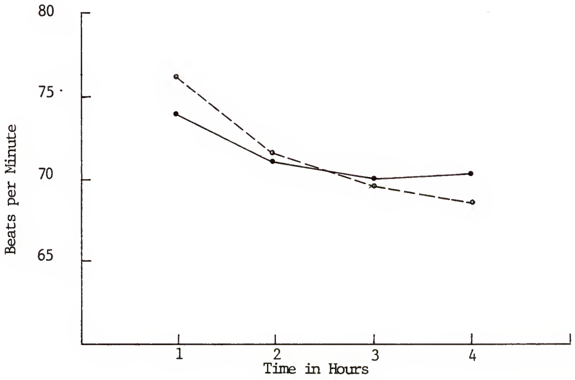
A= warm-white
B= broad-spectrum

Table 4

Marginal Means for Light-Time Combinations for Resting Heart Rate

	Hours			
	1	2	3	4
A	74.02*	71.26	70.14	70.50
B	76.47	71.76	69.73	68.64

A warm-white
B broad-spectrum
* claculated as the average of the means for each order



_____warm-white
-----broad-spectrum

Figure 1. Marginal Means for Light-Time Combinations for Resting Heart Rate

Table 5

Summary ANOVA Table for Systolic Blood Pressure

SV	SS	DF	MS	*F*	*P*
Order (O)	32.48	1	32.48	0.09	0.7611
Error	11057.54	32	345.54		
Light (L)	2376.52	1	2376.52	38.26	0.0000
OL	833.00	1	833.00	13.41	0.0009
Error	1987.72	32	62.11		
Time (T)	148.54	3	49.51	2.43	0.0700
TO	97.77	3	32.59	1.60	0.1947
Error	1956.92	96	20.38		
LT	332.79	3	110.93	6.48	0.0005
LTO	217.44	3	72.48	4.24	0.0074
Error	1642.51	96	17.10		

Table 6

Mean Scores and Standard Deviations for Systolic Blood Pressure

		Treatment Order AB				Treatment Order BA			
		Hour				Hour			
		1	2	3	4	1	2	3	4
A	X	113.00	113.70	115.58	118.70	112.11	111.00	110.94	110.17
	S	7.90	7.73	5.54	4.38	10.61	9.09	8.21	9.59
B	X	108.76	105.41	105.11	104.05	111.47	108.11	106.47	108.52
	S	6.15	6.68	7.40	8.45	10.69	8.41	7.17	8.28

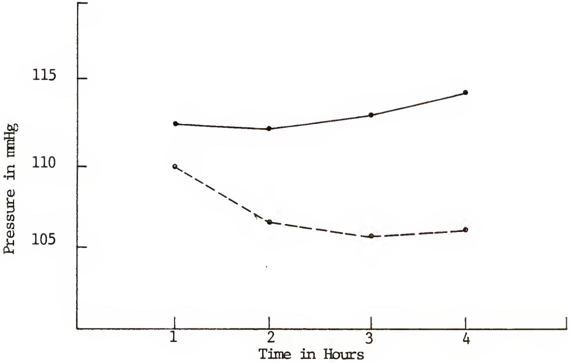
A= warm-white
B= broad-spectrum

Table 7

Marginal Means for Light-Time Combinations for Systolic Blood Pressure

	Hours			
	1	2	3	4
A	112.55*	112.35	113.26	114.44
B	110.11	106.76	105.79	106.29

A warm-white
B broad-spectrum
* calculated as the average of the means for each order



———warm-white
-----broad-spectrum

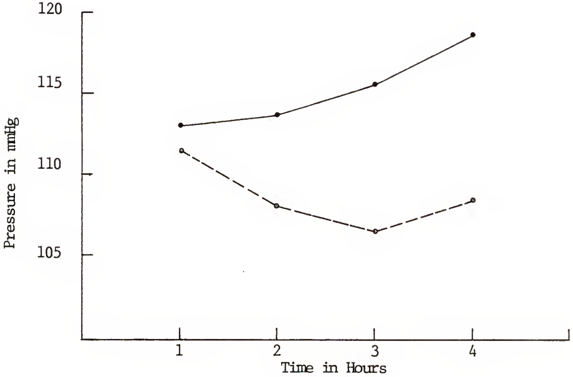
Figure 2. Marginal Means for Light-Time Combinations for Systolic Blood Pressure

Table 8

First Treatment Only Means for Light-Order Combinations for Systolic Blood Pressure

	Hours			
	1	2	3	4
A	113.00*	113.70	115.58	118.70
B	111.47	108.11	106.47	108.52

A warm-white
B broad-spectrum
* calculated as the average of the means for first treatment only



———warm-white
-----broad-spectrum

Figure 3. First Treatment Only Means for Light-Order Combinations for Systolic Blood Pressure

systolic blood pressure for the broad-spectrum condition was lower than the warm-white condition. Also the warm-white measurements rose every hour. The broad-spectrum measurements had a general decrease for the first three hours followed by a slight increase for hour four.

Diastolic blood pressure

Table 9 summarizes the ANOVA for the diastolic blood pressure measurements. Three sources of significant difference include the L effect, the T effect, and the LT interaction.

The LT interaction is analyzed in Table 11 and Figure 4. The broad-spectrum measurements were lower than the respective warm-white measurements. However, the trends of the two conditions were slightly different with the broad-spectrum curve dropping during the first three measures and increasing slightly on the fourth measurement and the warm-white increased for the first three measures and showed a very small decrease for hour four.

Pulse pressure

Table 12 summarixes the ANOVA for the pulse pressure measurements. Three sources of significant difference include the OL interaction, the T effect, and the LTO interaction.

Table 9

Summary ANOVA Table for
Diastolic Blood Pressure

SV	SS	DF	MS	F	P
Order (O)	101.30	1	101.30	0.22	0.6431
Error	14815.55	32	462.98		
Light (L)	1791.19	1	1791.19	23.61	0.0000
OL	13.23	1	13.23	0.17	0.6790
Error	2427.82	32	75.86		
Time (T)	232.23	3	77.41	3.80	0.0127
TO	27.22	3	9.07	0.45	0.7213
Error	1956.79	96	20.38		
LT	300.63	3	100.20	5.21	0.0022
LTO	18.47	3	6.15	0.32	0.8108
Error	1846.64	96	19.23		

Table 10

Mean Scores and Standard Deviations for
Diastolic Blood Pressure

		Treatment Order AB				Treatment Order BA			
		Hour				Hour			
		1	2	3	4	1	2	3	4
A	X	66.11	68.52	68.70	69.76	66.29	68.23	69.70	72.00
	S	10.31	9.64	8.64	7.21	10.87	10.85	10.04	9.58
B	X	63.11	62.94	61.29	63.47	65.70	63.88	62.47	65.41
	S	8.70	6.29	6.98	7.90	7.68	9.32	9.18	10.14

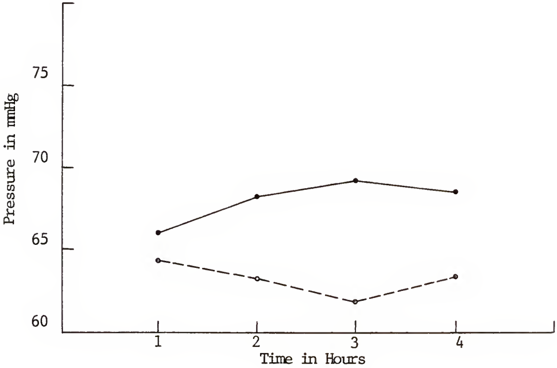
A= warm-white
B= broad-spectrum

Table 11

Marginal Means for Light-Time Combinations for Diastolic Blood Pressure

	Hours			
	1	2	3	4
A	66.20*	68.38	69.20	68.66
B	64.41	63.41	61.88	63.53

A warm-white
B broad-spectrum
* calculated as the average of the means for each order



———warm-white
-----broad-spectrum

Figure 4. Marginal Means for Light-Time Combinations for Diastolic Blood Pressure

Table 12

Summary ANOVA Table for Pulse Pressure

SV	SS	DF	MS	F	P
Order (O)	313.47	1	313.47	1.37	0.2510
Error	7338.89	32	229.34		
Light (L)	22.36	1	22.36	0.39	0.5351
OL	724.76	1	724.76	12.74	0.0012
Error	1820.36	32	56.88		
Time (T)	458.16	3	152.72	4.79	0.0037
TO	156.29	3	52.09	1.63	0.1866
Error	3061.04	96	31.88		
LT	54.27	3	18.09	0.55	0.6475
LTO	288.29	3	96.09	2.94	0.0372
Error	3141.92	96	32.72		

Table 13

Mean Scores and Standard Deviations for Pulse Pressure

		Treatment Order AB				Treatment Order BA			
		Hour				Hour			
		1	2	3	4	1	2	3	4
A	X	46.88	45.17	46.88	48.94	45.82	41.29	40.94	38.17
	S	8.28	7.96	8.13	5.84	7.63	7.11	7.93	8.36
B	X	45.46	42.47	43.82	40.58	45.76	44.11	44.58	42.52
	S	7.74	6.67	7.56	9.23	8.52	7.87	6.34	8.00

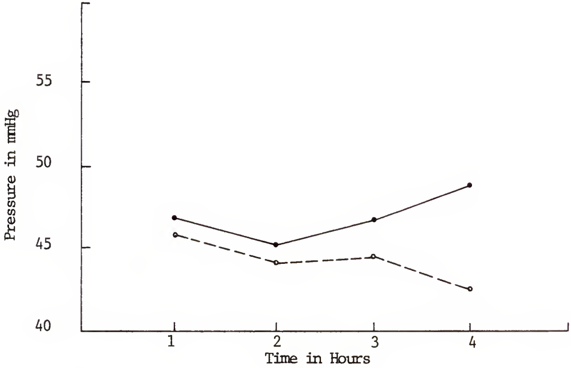
A= warm-white
B= broad-spectrum

Table 14

First Treatment Only Means for Light-Order Combinations for Pulse Pressure

	Hours			
	1	2	3	4
A	46.88*	45.17	46.88	48.94
B	45.76	44.11	44.58	42.52

A warm-white as first treatment
B broad-spectrum as first treatment
* calcualted as the average of the means for first treatment only



———warm-white
-----broad spectrum

Figure 5. First Treatment Only Means for Light-Order Combinations for Pulse Pressure

The interactions are analyzed on Table 14 and Figure 5. The second treatments for each group were ingored to disregard the order effect. All measures were lower under broad-spectrum than under warm-white. The curves followed the same trends for hours one, two, and three. However, for hour four the broad-spectrum pulse pressure measure decreased and the warm-white measure increased.

Visual acuity

Table 15 summarizes the ANOVA for the visual acuity measurements. There are no sources of significant difference.

Reaction time

Table 17 summarizes the ANOVA for the reaction time measuresments. Three sources of significant difference include the OL interaction, the T effect, and the LT interaction.

The LT interaction is analyzed in Table 19 and Figure 6. The broad-spectrum measurements showed a slight decrease over every hour. The warm-white measurements were constant for each hour.

Results of Exercise Test and Recovery

Table 20 lists the 15 variables and the respective treatment means and standard deviations.

Table 15

Summary ANOVA Table for
Visual Acuity

SV	SS	DF	MS	F	P
Order (O)	33486.48	1	33486.48	2.14	0.1529
Error	499728.82	32	15616.52		
Light (L)	16.01	1	16.01	0.33	0.5677
OL	72.05	1	72.05	1.50	0.2296
Error	1537.17	32	48.03		
Time (T)	60.32	3	20.10	1.05	0.3721
TO	24.48	3	8.16	0.43	0.7333
Error	1829.94	96	19.06		
LT	12.42	3	4.14	0.26	0.8568
LTO	41.44	3	13.81	0.85	0.4679
Error	1552.88	96	16.17		

Table 16

Mean Scores and Standard Deviations for
Visual Acuity

		Treatment Order AB				Treatment Order BA			
		Hour				Hour			
		1	2	3	4	1	2	3	4
A	X	45.0	44.0	44.5	45.0	21.7	21.4	21.1	21.5
	S	60.00	60.34	59.76	59.66	15.54	15.42	14.88	14.68
B	X	45.8	43.7	43.2	43.7	23.0	21.4	23.4	23.8
	S	60.78	60.93	60.88	60.65	15.28	15.46	21.74	22.44

A= warm-white
B= broad-spectrum

Table 17

Summary ANOVA Table for Reaction Time

SV	SS	DF	MS	F	P
Order (O)	0.003	1	0.003	0.37	0.5455
Error	0.28	32	0.009		
Light (L)	0.00001	1	0.00001	0.00	0.9536
OL	0.006	1	0.006	4.03	0.0532
Error	0.05	32	0.001		
Time (T)	0.01	3	0.004	7.49	0.0001
TO	0.008	3	0.002	4.76	0.003
Error	0.05	96	0.0005		
LT	0.005	3	0.001	2.83	0.0423
LTO	0.002	3	0.0007	1.21	0.3104
Error	0.06	96	0.0006		

Table 18

Mean Scores and Standard Deviations for Reaction Time

		Treatment Order AB				Treatment Order BA			
		Hour				Hour			
		1	2	3	4	1	2	3	4
A	X	0.36	0.36	0.37	0.36	0.37	0.36	0.35	0.36
	S	0.05	0.03	0.04	0.05	0.03	0.04	0.03	0.04
B	X	0.36	0.35	0.34	0.35	0.42	0.37	0.35	0.36
	S	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.02

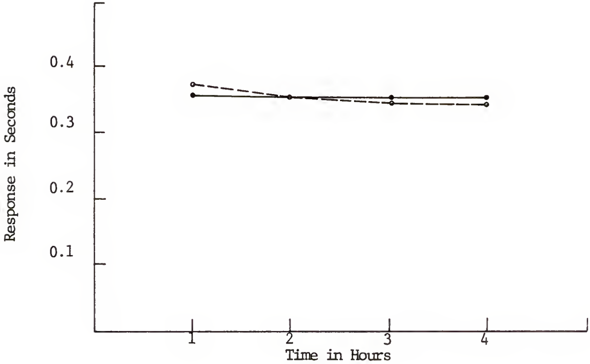
A= warm-white
B= broad-spectrum

Table 19

Marginal Means for Light-Time Combinations for Reaction Time

	Hours			
	1	2	3	4
A	0.36*	0.36	0.36	0.36
B	0.38	0.36	0.35	0.36

A warm-white
B broad-spectrum
* calculated as the average of the means for each order



———warm-white
-----broad-spectrum

Figure 6. Marginal Means for Light-Time Combinations fro Reaction Time

Table 20

Mean Values for Exercise Test Variables

	Warm-White		Broad-Spectrum	
Variable	Mean	SD	Mean	SD
Systolic Blood Pressure $_{6\ \text{min.}}$	147.76	13.06	155.99	14.45
Diastolic Blood Pressure $_{6\ \text{min.}}$	79.07	7.45	79.70	8.45
Pulse Pressure 6 min.	68.69	11.72	76.29	15.65
Heart Rate $_{6\ \text{min.}}$	156.23	15.53	150.47	17.22
Systolic Blood Pressure $_{\text{final}}$	151.55	13.43	160.70	15.41
Diastolic Blood Pressure $_{\text{final}}$	87.70	6.93	83.94	9.05
Pulse Pressure final	65.55	11.48	77.47	9.73
Heart Rate $_{\text{final}}$	178.82	2.21	177.00	2.17
Predicted Max. Oxygen Uptake	24.67	5.72	26.24	6.31
Time on Bike	6.50	1.74	6.97	1.71
PWC_{170}	4229.40	764.38	4780.29	812.73
Half Life Recovery	123.54	61.34	131.10	81.72
Recovery Heart Rate $_{1\ \text{min.}}$	135.00	13.53	135.70	12.85
Recovery Heart Rate $_{3\ \text{min.}}$	107.41	10.57	106.94	11.28
Recovery Heart Rate $_{5\ \text{min.}}$	94.94	7.30	94.05	6.94

Table 21

t Values for Exercise Test Variables

Variable	*t* value	DF	Sig.	Level
Systolic Blood Pressure$_{6\ \mathrm{min.}}$	1.10	26	NO	$<.05$
Diastolic Blood Pressure$_{6\ \mathrm{min.}}$	1.45	26	NO	$>.05$
Pulse Pressure 6 min.	1.68	26	NO	$>.05$
Heart Rate$_{6\ \mathrm{min.}}$	2.41	26	YES	$<.05$
Systolic Blood Pressure$_{\mathrm{final}}$	1.27	33	NO	$>.05$
Diastolic Blood Pressure$_{\mathrm{final}}$	1.08	33	NO	$>.05$
Pulse Pressure final	3.52	33	YES	$<.01$
Heart Rate$_{\mathrm{final}}$	0.00	33	NO	$>.05$
Predicted Maximal Oxygen Uptake	2.25	33	YES	$<.02$
Time on Bike	2.36	33	YES	$<.05$
PWC$_{170}$	1.30	33	NO	$>.05$
Half Life Recovery	1.01	33	NO	$>.05$
Recovery Heart Rate$_{1\ \mathrm{min.}}$	0.07	33	NO	$>.05$
Recovery Heart Rate$_{3\ \mathrm{min.}}$	0.62	33	NO	$>.05$
Recovery Heart Rate$_{5\ \mathrm{min.}}$	0.87	33	NO	$>.05$

Table 21 is a composite listing of the t values for each of the 15 variables measured in this study and the level of significance if any, between the treatment means. Four variables were found to be significant at the .05 level, all favoring the broad-spectrum condition: heart rate at six minutes, final pulse pressure, predicted maximum oxygen uptake, and time on bike.

Discussion of Results

The results obtained in this study support the hypothesis that a four-hour exposure to a broad-spectrum light results in a gradual decrease in resting heart rate, systolic blood pressure, diastolic blood pressure, and pulse pressure when compared to equal exposure to standard warm-white fluorescent lighting. The results also support the hypothesis that a four-hour exposure to a broad-spectrum light results in a decrease in heart rate after six minutes of exercise, an increase in pulse pressure at the termination of exercise, an increase in predicted maximal ozygen uptake and an increase in the length of time an individual can exercise when compared to equal exposure to standard warm-white fluorescent lighting.

This study showed a general lowering of the subjects' resting heart rates over the four-hour exposure period. The effect was more dramatic under the broad-spectrum condition.

A lowering of heart rate could be an indication of less environmental stress on the individual.

The effects of light on systolic blood pressure was a slight increase in the measurement under the warm-white lighting. The broad-spectrum effect was a gradual lowering of the systolic blood pressure. This indicates that the individual received less stress under the broad-spectrum condition.

The effects of light on diastolic blood pressure was similiar to the systolic effects as all measures were lower under the broad-spectrum conditions. Also the diastolic blood pressure measure generally showed a decrease over time. Again this is perhaps an indication that broad-spectrum light exerts less of a stress than warm-white light on the cardiovascular system of the human body.

The effects of lighting condition on the pulse pressure measure was again a lower measure over time under the broad-spectrum treatment. This difference could be predicted as the pulse pressure is directly related to the systolic and diastolic measures.

There were no significant effects when comparing the visual acuity measures. A Snellen chart is merely a screening device for visual acuity. Therefore, a more discrete measuring device could better measure the variable of eye fatigue.

The reaction time data revealed a slight difference between the two treatments. However, the differences are not statistically significant. the general trend is interesting to view as there is a general improvement in reaction time under the broad-spectrum condition. A better test would be to have a more complex activity than the one chosen for this study.

The exercise test data revealed four major areas of interest: heart rate after six minutes of exercise, final exercise pulse pressure, predicted maximal oxygen uptake, and time on bike.

The heart rate after six minutes of exercise indicates a steady state at the prescribed workload. The six-minute heart rate was lower under the broad-spectrum than under the warm-white condition. This difference indicates that the subject was able to perform a prescribed workload with less stress on the heart at the six-minute mark when under broad-spectrum as compared to warm-white.

Predicted maximal ozygen uptake was higher for the broad-spectrum treatment than for the warm-white treatment. The greater the maximal oxygen uptake, the greater the potential energy output. Thus the predicted level of fitness was higher for the broad-spectrum treatment.

Time on bike was also greater for the broad-spectrum treatment than for the warm-white treatment. This suggests that fatigue sets in faster under the warm-white lighting when compared to broad-spectrum light.

The recovery time collection technique was not adequate. All measurements were taken by hand. This type of instrumentation could drastically effect the results. The plotted half lives revealed that there was not an exponential "decay" in the recovery rates. However, as a precaution for subject safety it was a valid means of measurement.

CHAPTER 5
DISCUSSION AND CONCLUSIONS

In this study several hypothesis concerned with the effects of fluorescent lighting on human health were investigated. The focus was on the possible differences between performance responses (both at rest and exercise) when exposed to different types of fluorescent light spectra. The data was analyzed as to the effectiveness of one light over another.

Significance

All radiations (visible and invisible) are distinguished by the fact that they exercise a more or less profound effect on the human body. This means that light is quite essential to a healthful and normal life. Light effects the body through the tissues of the skin and through the eyes. As the result of absorption of radiant energy chemical changes in matter are brought about.

Biren (1969, p.9) suggests that "the day is here in which lighting for biological purposes will supplant or at least supplement lighting for mere purposes of vision." The findings in the present study support the theory that light is indeed an environmental stress that can alter human performance. Considerations for classroom lighting must go beyond the idea of light only for vision.

Researchers and educators are faced with the problems of describing and implementing the best environmental controls for today's students. Light is an often neglected aspect of the classroom environment. The purpose of the present study was to investigate the question of which type of fluorescent light should be recommended for classrooms.

Implications

This project demonstrates that human performance responses are indeed different under two types of fluorescent lights. When the light closely duplicates the spectra of sunlight the responses are generally better than under ordinary fluorescent lighting.

The findings have implications for both the classroom teacher and the physical educator. The length of exposure is of concern to all teachers. As a school day progresses the student's responsiveness should not be hindered because of environmental deficiencies in a classroom. As the student sits in the classroom there are environmental inputs which can effect the eventual performance in a physical education class.

Students need to be made aware that light is an important environmental input. Possible areas for study are in the natural sciences and psychology. The teacher's general knowledge and attitude toward classroom lighting will be reflected in the students.

Facilities and their maintenance and improvement are another area for lighting research. One aspect of the present study suggests that one solution is a mere "re-tooling" of fluorescent light tubes in schools and other public buildings.

Conclusions

The following conclusions can be drawn based upon the results of this study:

1. Mean resting systolic and diastolic blood pressure, and pulse pressure are lower under broad-spectrum fluorescent light.
2. Light spectra has no effect on visual acuity or reaction time with four hours of exposure.
3. Heart rate after six minutes of exercise is lower with exposure to broad-spectrum light.
4. Pulse pressure after termination of exercise is greater with exposure to broad-spectrum light.
5. Predicted maximal oxygen uptake is greater with exposure to broad-spectrum light.
6. The length of time on bike was extended with exposure to broad-spectrum light.

Suggestions for Further Research

The number of possibilities for further research in the area of the effects of fluorescent lighting on human performance are quite unfathomable. All areas of performance currently researchable could be modified for study with light.

Specific lighting concerns include lights with yet other spectral outputs, radiation shielding in fluorescent lights, intensities of lights, and length of exposure.

Longitudinal studies need to be performed to find long term effects of light on the performance of school children. Developmental characteristics and the possible relationship to light needs to be studied.

Interdisciplinary communication will be one of the major keys to progress in research in the area of light's effect on the basic life processes (Ott, 1982, p.18). Environmental concerns are no longer the concerns of a few scientists. All human beings need to be educated in the area of environmental studies.

Summary

The results of this study indicate that broad-spectrum light has no ill-effects on human performance when compared to warm-white fluorescent light. The selected battery of tests suggest that differences can be found in resting measurements throughout a four-hour period and that light also effects exercise measures after a four-hour exposure. Therefore, broad-spectrum light is recommended for use in classrooms.

APPENDIX A

CONSENT FORM

I ____________________ agree to participate in an experiment conducted by Rene' Chance that will attempt to find information as to the effects of two types of fluorescent lights on human fitness and performance. The information gained from this experiment will be used to determine which, if either, of the lights will significantly effect the following performance variables: resting heart rate and blood pressure, reaction time, visual acuity, PWC_{170}, exercise blood pressure, and heart rate recovery. The experiment will take place at Palm Beach Atlantic College during the spring semester of 1982.

On two different days I will stay in the assigned room 4½ hours during which time I will be tested hourly (four times) for resting heart rate and blood pressure, reaction time, and visual acuity. During the final hour of each session I will perform a stress test on a bicycle ergometer which will attempt to raise my heart rate to 170. I will help in the administration of the tests to other subjects.

I will monitor my food intake on the morings of the experiment and duplicate my diet as far as possible. I will not wear eyeglasses, sunglasses, or contact lenses during the testing.

I understand that no monetary compensation is being offered for my participation in this study. I further understand that all personal information will be kept confidential and will only be used in screening the subjects for anything that might interfere with the experiment.

I understand if I am physically injured during this experiment, and if the experimenter is at fault, that I may seek appropriate eompensation and my contact the Insurance Coordinator for information about compensation at 107 Tigert Hall, University of Florida, telephone number 392-1325. I understand that no other form of compensation is available.

I have read and I understand tha procedure described above, I agree to participate in theprocedure but with the condition that I may withdraw this consent or discontinue participation at any time without prejudice towards me. I agree to participate in the procedure and I have received a copy of this description.

____________________ Subject	__________ Date	____________________ Witness	__________ Date
____________________ Relationship if other than subject	__________ Date	____________________ Principal Investigator's name and address	__________ Date

APPENDIX B
INDIVIDUAL DATA SHEET

SUBJECT I.D.   ORDER OF TREATMENT   WEIGHT

			HOUR				HOUR	
VARIABLE	1	2	3	4	1	2	3	4
Resting Heart Rate								
Resting Blood Pressure								
Pulse Pressure								
Visual Acuity								
Right								
Left								
Both								
Reaction Time								
Tr. 1								
Tr. 2								
Tr. 3								
Mean								

APPENDIX C
PWC (170) DATA

SUBJECT I.D. ORDER OF TREATMENT WEIGHT

TRIAL 1					TRIAL 2				
LOAD	MIN.	H.R.	B.P.	P.P.	LOAD	MIN.	H.R.	B.P.	P.P.
	1					1			
	2					2			
	3					3			
	4					4			
	4					5			
	5					5			
	6					6			
	7					7			
	8					8			
	9					9			
	10					10			
	11					11			
	12					12			
	13					13			
	14					14			
	15					15			
	16					16			
	17					17			
	18					18			

APPENDIX D
HEART RATE RECOVERY DATA

SUBJECT I.D. ORDER OF TREATMENT WEIGHT

HEART RATE	TRIAL 1	TRIAL 2
Maximum	________	________
10 sec.	________	________
20 sec.	________	________
30 sec.	________	________
40 sec.	________	________
50 sec.	________	________
1 min.	________	________
10 sec.	________	________
20 sec.	________	________
30 sec.	________	________
40 sec.	________	________
50 sec.	________	________
2 min.	________	________
10 sec.	________	________
20 sec.	________	________
30 sec.	________	________
40 sec.	________	________
50 sec.	________	________
3 min.	________	________
10 sec.	________	________
20 sec.	________	________
30 sec.	________	________
40 sec.	________	________
50 sec.	________	________
4 min.	________	________
10 sec.	________	________
20 sec.	________	________
30 sec.	________	________
40 sec.	________	________
50 sec.	________	________
5 min.	________	________

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BIOGRAPHICAL SKETCH

René E. Chance, born March 2, 1955, in Pensacola, Florida, is a lifelong Florida resident and is a product of Florida education. After attending public schools in Pensacola and Sanford, she enrolled as an advanced admissions student at Stetson University where she received the Bachelor of Arts degree in 1976.

At the University of Central Florida, Orlando, Ms. Chance became a graduate assistant and worked with student teachers in the Physical Education Department. She was awarded the Master of Education degree in 1978.

Continuing in the field of educaiton, Ms. Chance gained career experience as a physical education teacher in the public school system of Seminole County. She was also a classroom teacher at a private Christian school in Orlando.

In 1980 Ms. Chance began the doctoral program at the University of Florida and in 1982 she completed the Ed.D. program, majoring in Curriculum and Instruction. During this period she joined the faculty at Palm Beach Atlantic College in West Palm Beach in the Physical Education Department.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Education.

Gordon D Lawrence

Gordon D. Lawrence, Chairman
Professor of Instructional
Leadership and Support

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Education.

James J. Algina

James J. Algina
Associate Professor of
Foundations of Education

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Education.

Robert E. Allen

Robert E. Allen
Professor of Professional
Physical Education

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Education.

Christian W. Zauner

Christian W. Zauner
Professor of Professional
Physical Education

This dissertation was submitted to the Graduate Faculty of the Division of Curriculum and Instruction in the College of Education and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Education.

August, 1982

Dean for Graduate Studies
and Research